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A new signal of marine tropicalization in the Macaronesia region: First record of the mesophotic macroalga *Avrainvillea canariensis* A. Gepp & E.S. Gepp in the Madeira archipelago

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ABSTRACT

Mesophotic green algal meadows of *Avrainvillea canariensis* are firstly reported for Madeira island. This represents a northern expansion of the species by nearly 500 km turning the species a Macaronesian endemism. The meadows of *A. canariensis* were found in a sandy bottom in the South coast of the island of Madeira, inside the Marine Park of Cabo Girão, covering an estimated area of 50 m^2 at a depth range 25–30 m. The collected specimens reached about 12 cm in height and were found clustered, forming distinct patches. Since this type of subtidal surveys in soft bottoms are scant in Madeira, we cannot evaluate whether this is a recent colonization. Yet, this new record can be another clear sign of climate change effects in the madeiran benthic communities, a process previously documented in the Macaronesia region with the arrival and subsequent settlement of other warm water marine species.

1. Introduction

Certain groups of algae are well adapted to grow in the mesophotic zone (low-light), and form conspicuous deep-water algal assemblages (Zechman et al., 2010; Spalding, 2012; Spalding et al., 2016). Among them, the green algae Bryopsidales (e.g. *Halimeda*, *Codium*, *Caulerpa*, *Udotea,* and *Avrainvillea*) are often particularly abundant, and may form continuous beds or meadows (Freile et al., 1995; Leichter et al., 2008; Spalding, 2012).

The genus *Avrainvillea* Decaisne, 1842, belonging to family Dichotomosiphonaceae (Verbruggen et al., 2009) and order Bryopsidales, currently comprises 30 species (Guiry and Guiry, 2018). This tropical to subtropical genus monographed by Olsen-Stojkovich (1985) and some years later by Littler and Littler (1992), is characterized by uncalcified erect thalli generally divided in three parts: (1) a basal rhizoidal mass (= holdfast) anchored to rock or, more often, immersed in soft substrata; (2) an upright corticated stalk (= stipe); and (3) a fan-shaped terminal blade (= flabellum).

A. canariensis A. Gepp & E. S. Gepp is the only documented species of this genus that occurs in the East Atlantic and, until now, its distribution was limited to the Canary Islands (Gallardo et al., 2016), where the species was considered a neoendemism, i.e. a species that has never been found outside its place of origin (Cabrera and Suárez, 2006; Gallardo et al., 2016).

The marine seaweed flora of the Madeira islands is less diverse than that of the Canary Islands (359 species versus 690 listed by Neto et al. (2001) and Gallardo et al. (2016) respectively). Despite the geographical and ecological differences between these two Macaronesian archipelagos that might explain some differences in algal species diversity, Madeira has also been the subject of a lesser scientific research effort, particularly in subtidal habitats. In effect, the lack of consistent sampling in Madeira has been pointed as a possible reason for the underestimation of the seaweed species number of this region (Ferreira, 2011). Moreover, thorough collections in subtidal bottoms and deeper waters of Madeira have not been carried out, and studies on the mesophotic zone of Madeira coastal ecosystems are either scant and completely opportunistic, or have focused on particular groups (e.g. Echinoderms — de Jesus and Abreu (1998), Molluscs — Swinnen et al. (1998); Hydrozoa — Medel and Vervoort (2000)).

Apart from the checklist of Neto et al. (2001), new algae records

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from Madeira are sporadic, focused on a particular group of algae or resulted from studies targeting the Macaronesian region (e.g. Haroun et al., 2002; Afonso-Carrillo et al., 2006; Tronholm et al., 2010; Sala et al., 2013; Rosas-Alquicira et al., 2011; Ferreira, 2011; Ferreira et al., 2012; Machín-Sánchez et al., 2016, 2018). Additionally, deep-water algal meadows (*Halimeda incrassata* and *Penicillus capitatus*) in Madeira archipelago, have only been observed in Porto Santo island, where light levels from surface irradiance at depths > 20 m are higher than in Madeira (C. Ribeiro and P. Neves, pers. obser.).

The Madeira archipelago is located in the subtropical North-Eastern Atlantic Ocean and comprised the islands of Madeira and Porto Santo as well as the uninhabited islets of Desertas. Madeira's dominant oceanic currents are the Portuguese, Azores, and Canary Currents, all part of the eastern anticyclonic North Atlantic subtropical gyre (Sala et al., 2013) which results in high salinity, high temperature and low-nutrient regime waters (Johnson and Stevens, 2000; New et al., 2001). Surrounded by oceanic waters, Madeira is characterized by a reduced continental shelf and its subtidal substrates (from the coastline to approximately 20 m isobath) are mainly dominated by rocky reefs (Ribeiro, 2008).

According to the classification of the Marine ecoregions of the world (Spalding et al., 2007), Madeira is included in the ecoregion Azores-Madeira-Canaries within the Lusitanian province and if considered the realignment of marine biogeographic provinces proposed by Briggs and Bowen (2012), all these archipelagos, are included in the Lusitanian province within the Eastern Atlantic Region. Among the Lusitanian Macaronesian archipelagos, Tuya and Haroun (2009) demonstrated that seaweed richness peaked at the Canary Islands and decreased towards the Azores, matching a progressive increase in distance from the nearest continental shores.

The worldwide distribution patterns of macroalgae are mainly determined by global temperature gradients (Lüning et al., 1990) and as result of its geographical location, new records of tropical species in Madeira island may reflect the climate change effects over the local subtidal benthic communities. Indeed, recording biodiversity with precise taxonomic identifications improves efforts to understand ecosystem structure and functioning as well as contributes to the development of management tools (Bruno et al., 2005; Costello et al., 2013).

In that line, this contribution reports and describes a new macroalga for the Madeira archipelago and provides ecological data concerning this new subtidal mesophotic habitat in soft-bottoms.

2. Material and methods

SCUBA surveys were performed on May 2018 to study the subtidal habitats of the recently created Cabo Girão Marine Park (CGMP) at the south coast of Madeira. Visual surveys were conducted along eight 30 × 2 m transects in order to estimate the number of patches of *A. canariensis*. Patch area was inferred from two measurements (maximum length and maximum width). Density of thalli for each of the two major patches was obtained from counts inside four 25 × 25 cm photo-quadrats.

The *Avrainvillea* samples were collected inside CGMP (32° 38.870′ N, 16° 59.605′ W) on two survey occasions (May 10th and 17th, 2018) and underwater pictures of the meadow were taken on both occasions (Plate 1 A). The collected samples were photographed while fresh, and preserved (one halve as herbarium vouchers and the other halve preserved in Kew solution — 40% ethanol, 40% seawater, 10% glycerin and 10% formalin). Voucher specimens are deposited at. AZB (herbarium of the University of the Azores) and at Funchal Natural History Museum herbarium with, respectively, the numbers: AZB-MAD-2018-1, AZB-MAD-2018-2 and MADM 6979.

The taxonomic characters used for *Avrainvillea* species identification follow the review by Littler and Littler (1992) and include, e.g. frond shape and size; thalli structure and organization (including the rhizoidal base, corticated stipe, and fan-shaped blade), and the siphons morphology and size. According to Littler and Littler (1992) one should prefer the term siphon to filament since this later is normally defined as a chain of cells attached end to end, which cannot be applied to completely siphonous algae such as *Avrainvillea*. For morphological and anatomical characterization, whole specimens or slide preparations were observed and taxonomically relevant structures were measured using a calibrated micrometre eyepiece. Microscopic photographs were made using a digital camera (Olympus model C5060, Japan) attached to a light microscope (Olympus model BX50 F, Japan).

3. Results and discussion

3.1. Habitat characterization

The subtidal habitats inside the CGMP are characterized by rocky reefs, which can reach depths down to 40 m and cover nearly 50% of the total protected area. Extensive sandy bottoms also occur at the eastern side, the shallower of them, at a depth of 8 m. Individuals of the green macroalga *Avrainvillea canariensis* forms scattered patches of roughly 9 m^2 — at least 6 patches were observed covering an estimated total area of 50 m^2 (patches ranging from 4 to 15 m^2), at depths between 29 and 27 m. The denser patches forms meadows with thalli densities ranging from 640 to 1360 individuals/m^2 (Plate 1 A). Isolated specimens were also observed in the area, at depths ranging from 29 m to 22 m, 30 m being maximum depth of the dives.

3.2. Species description

Solitary greenish fan-shaped thalli up to 12 cm total height (Plate 1 A–C), each one composed of an elongated, 4.5–8 cm long, simple, and somewhat compressed rhizoidal base (Plate 1 B,C), buried in the sandy bottom, and a paddle shaped, thin, and very lightly zoned frond with a spongy structure (Plate 1 B,C), 2–4 cm long × 1.6–3.9 cm wide. With a siphonous organization, the thallus is compounded of cylindrical siphons, the external ones non-differentiated in utricles (Plate 1 D–G). These siphons are green or some-how golden-green, 25–58 µm in diameter in the upper part of the frond, presenting even now and then slightly flattened dichotomies (Plate 1 F,G); those siphons are slightly broader: 37.5–60 µm in diameter and much less-pigmented in the rhizoidal part of the thalli (Plate 1 D,E).

3.3. Discussion

This new record for *A. canariensis*, forming mesophotic meadows inside the CGMP, confirms the existence of a newly discovered subtidal habitat in the soft subtidal bottoms of Madeira island and represents a northern expansion of the species of nearly 500 km. Thus, *A. canariensis* extends its distributional pattern towards the Macaronesian archipelago of Madeira and becomes another Macaronesian marine endemism, losing its Canarian endemic status (Cabrera and Suárez, 2006; Gallardo et al., 2016).

Although, long data-series on environmental factors for the Madeira archipelago do not exist, the *A. canariensis* expansion is considered as a new signal of climate change effects on the benthic communities in the Macaronesia region, as reported by Ferreira et al., (2012) for three new macroalgae species (*Cladophora lehmanniana*, *Cystoseira wildpreti*, *Sargassum furcatum*). Similar changes have also been reported to the Madeira marine fauna with the arrival of tropical species during the last two decades (e.g. Araújo and Freitas, 2002; Araújo, 2002; Araújo and Freitas, 2003; Wirtz, 2005). This situation has also been observed in the Canary Islands, where the proportion of tropical elements has increased in the marine flora and fauna (Brito et al., 2005; Brito and Falcón, 2006; Afonso-Carrillo et al., 2007; Cassano et al., 2008), possibly due to global warming (Brito, 2008).

Although some macroalgal sampling efforts were done in the southern coast of Madeira in the late 90's and during the Macaronesia

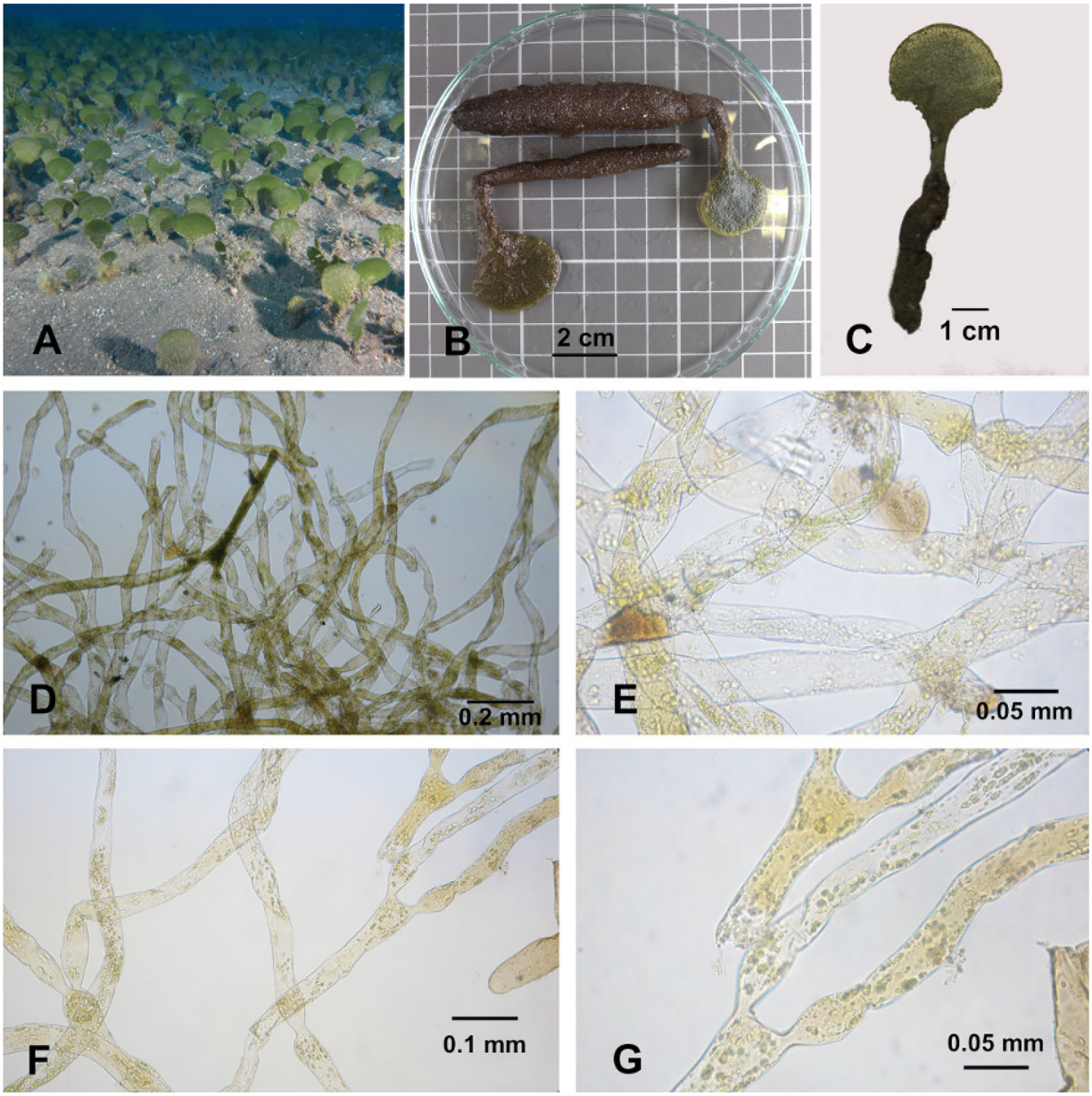

Plate 1. *Avrainvillea canariensis*: fan-shaped thalli in situ (A); thallus habit (B and C); upper thallus siphons x10 (D); rhizoidal base siphons x40 (E); thallus siphons x20 (F); flattened dichotomies in thallus siphons x40 (G).

2000 Expeditions to Porto Santo and Madeira islands (Cruz-Reyes et al., 2002; Haroun et al., 2002), we cannot discard the hypothesis that the finding of this mesophotic macroalga and its associated subtidal habitat is just a consequence of the limited marine research conducted until now in the Madeira archipelago.

It is likely that the species may occur in other locations and, therefore, further research, including multiple locations in mesophotic meadows of Madeira are recommended to evaluate if *A. canariensis* has spread to other locations and to determine its importance as a possible new marine ecosystem in Madeira.

The specimens of *A. canariensis* described are smaller than the ones reported to the Canaries by Afonso Carrillo et al. (1984; 12 cm in Madeira vs 18 cm in the Canaries). However, larger specimens were observed in situ by the authors (C. Ribeiro and P. Neves), but not collected to avoid destructive sampling. Interestingly the species, although occasionally can occur isolated, forms patches in Madeira, contrarily to the occurrence of isolated individuals referred to the Canary Islands by Haroun et al. (2003).

The discovery of the mesophotic species *Avrainvillea canariensis* in the South coast of Madeira Island stresses the need for further research aimed at understanding the dynamics of the mesophotic ocean zone and particularly of its macroalgal community composition in order to understand the extent and importance of this habitat in Madeira.

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